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Title: ULTRASONIC FREQUENCY DIFFERENCE GERNERATION TO CHARACTERIZE FUIDS IN A SATURATED BEREA SANDSTONE

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ULTRASONIC FREQUENCY DIFFERENCE GENERATION TO CHARACTERIZE FLUIDS IN SATURATED BEREA SANDSTONE

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Abstract – The use of nonlinear acoustics to characterize fluids in porous media is presented. The acoustic nonlinearity in sandstone is affected by the presence of water or oil. This difference in properties that affect the sound propagation through such media can be used to determine whether a piece of sandstone contains water or oil. Traditional methods of characterizing porous media usually rely on the transmission or reflection of a single ultrasonic probe pulse. The technique presented in this paper uses a method of generating a probe pulse inside the porous medium from the interaction of two pulses. Information about the medium is then contained in the propagation of this probe signal back to a receiver. The main advantage of this approach is that it allows implementation of this technique inside a borehole for characterizing the porous media outside.

I. INTRODUCTION

Mapping out or otherwise characterizing underground rocks that may be saturated with liquid or brine is important for the petroleum industry so that oil can be extracted from wells in a cost effective and efficient manner. Therefore, it is important to know the nature (saturation characteristics) of the porous rock (e.g., Sandstone) around a borehole. Porous media that contain fluid (e.g., water, oil, etc.) provide a rich but complicated system to study[1-3]. Due to the physical constraints imposed by such systems, ultrasonic techniques have certain advantages over other techniques. Though most traditional ultrasonic methods have been based on linear acoustics, they have shown their ability to be very useful in many situations. In this paper, we present a nonlinear acoustic technique that tries to address the need of the petroleum industry. In this technique, the differences in the nonlinear acoustic properties of the components of the system are used to perform imaging. This is a relatively new approach and shows promise as another tool for the characterization of fluid saturated porous media.

We have studied Berea sandstone containing water and oil using the differences in the linear and nonlinear acoustic properties of these materials. One major advantage of this technique is that the pump, probe and receiver transducers are all on the same side of the rock sample, which makes it potentially suitable for implementation inside a wellbore. This technique relies on a signal being generated inside the medium as opposed to being injected externally. The propagation time of this signal back to the receiver gives information about the distance inside the medium being probed. This technique is very similar to the non-contact technique for making standoff measurements in air at large distances where the nonlinear properties of air are used to demodulate a propagating ultrasonic wave[4].

The nonlinear measurements rely on the fact that superposition doesn't hold, as opposed to the linear case. To measure the nonlinear signal, first a low frequency pump ultrasonic wave (tone burst) is sent out by itself, and the resulting received waveform is recorded. Next a higher frequency probe wave (burst) by itself is sent out and recorded. Then both are sent out simultaneously and the resulting waveform recorded. The resulting nonlinear signal is then the difference between the received signal when both pump and probe waves are on and the sum of each received signal with the pump and the probe waves being turned on separately. The time delay of the generated signal due to nonlinear frequency mixing getting back to the receiver allows for the analysis to determine the position inside the rock being probed. The interaction region between the pump and the probe waves can be moved through the rock simply by adjusting the relative delay between the transmission of the pump and probe tone bursts.

II. EXPERIMENTAL SETUP

The pump and probe function generators and amplifiers are both contained in the Ritec RAM5000 SNAP instrument[5]. This device is normally used with its internal mixer to determine sum and difference frequency amplitudes of the received waveforms directly. However, we found it advantageous to record the whole waveform, as the processes involved produce appreciable frequency component amplitudes in the received waveform at the pump and probe frequencies also. This instrument is also able to control the time delay between the two signals. The waveforms are recorded on a Lecroy digital oscilloscope (Model LT224). To achieve higher signal-to-noise (S/N) ratios the received signal was averaged. Though the Ritec unit is capable of producing up to 5kW pulses, the frequency ranges used in these experiments was outside the normal operating range of the instrument. Typical pump and probe pulses used were 20-100 W.

Rectangular shaped Berea sandstone was used as the porous medium in these experiments. The sandstone measured 600mm x 200 mm x 50 mm. The transducers were placed as shown in Figure 1, the receiver being between the pump and probe sources. The pump source was a Panametrics X1020 100-kHz transducer, and the probe was a Panametrics V101 500-kHz transducer. The pump frequency was 110 kHz and consisted of a single cycle burst from the amplifier. The probe frequency was either 150, 200 or 300 kHz and was also a single cycle. The higher attenuation at higher frequencies inside the sandstone precluded using frequencies that more closely matched the amplifiers maximum power response. It is anticipated that using higher power would allow for a better S/N ratio of the received signals to be achieved.

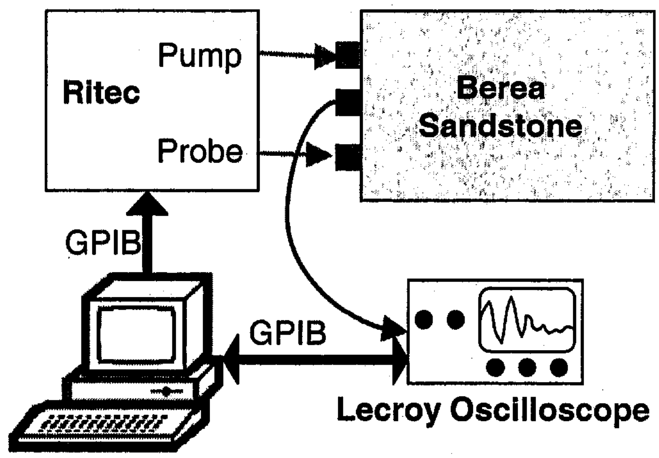

Figure 1. Experimental Setup. The Ritec instrument acts as the signal source to the transducers. The oscilloscope records the resulting signals.

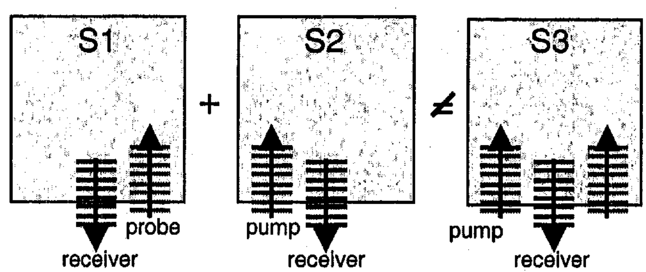

Figure 2. Measurement 1 is just the probe signal getting back to the receiver. Measurement 2 is just the pump. Measurement 3 is both being on at the same time. Any signal generated inside the rock will show up as a difference between both pump and probe being on separately and both on simultaneously.

A typical experiment starts with the rock free of water or oil. The nonlinear signal was first determined for the dry rock. Water or oil (10W-30 motor oil) was then placed in the rock near the center. After the sandstone sample showed signs of being wetted thoroughly, no additional water or oil was placed in the rock to allow the system to reach equilibrium. A set of measurements was then taken. As mentioned earlier, the time it takes for the nonlinear portion of the signal to propagate back to the receiver is related to the position in the rock where the signal was generated. The results are shown in Fig. 3 for water and Fig. 4 for oil. From these results, it is clearly seen that the presence of water and oil has a dramatic effect on the amplitude of the nonlinear signal that is generated inside the rock that gets back to the receiver. The location of the drop in signal amplitude corresponds to the location of the fluid boundary as evident on the surface of the rock.

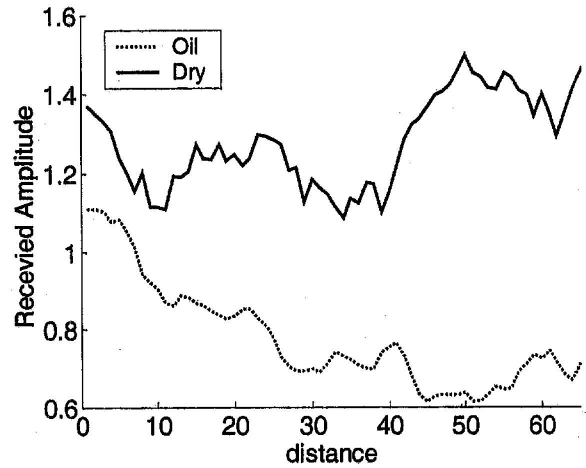

Figure 4. The nonlinear signal amplitude returning from dry and oil-saturated the rock as a function of distance. The oil-saturated rock clearly shows a decrease in the amount of signal as it propagates further into the rock.

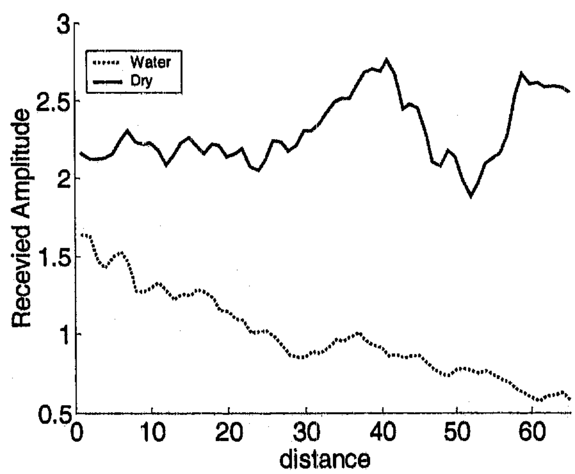

Figure 3. The nonlinear signal amplitude returning from the dry and water-saturated rock as a function of distance. The water-saturated rock clearly shows a decrease in the amount of signal as it propagates further into the rock.

Some possible mechanisms for this drop in signal amplitude include the following. (1) Attenuation of the probe pulse as it travels to the interaction region, (2) attenuation of the pump pulse as it travels to the interaction region, (3) attenuation of the generated signal as it propagates to the receiver, and (4) different nonlinear signal generation efficiencies between wet and dry rock. Though all these mechanisms may contribute to the difference in nonlinear signal amplitudes between fluid saturated and dry rock, making the analysis difficult, this technique shows promise in characterizing fluid saturated porous media.

We are currently investigating the possibility of steering the interaction region to different parts of the system by delaying or advancing the probe pulse relative to the pump. Only those regions will produce a nonlinear signal, and therefore should allow us to map out the rock. Figure 5 shows the interaction region as the pump wave is delayed, the same, or advanced relative to the probe wave. The steering caused by changing the relative delay, and the propagation delay of the generated signal should allow for a mapping of the properties of the system to be performed.

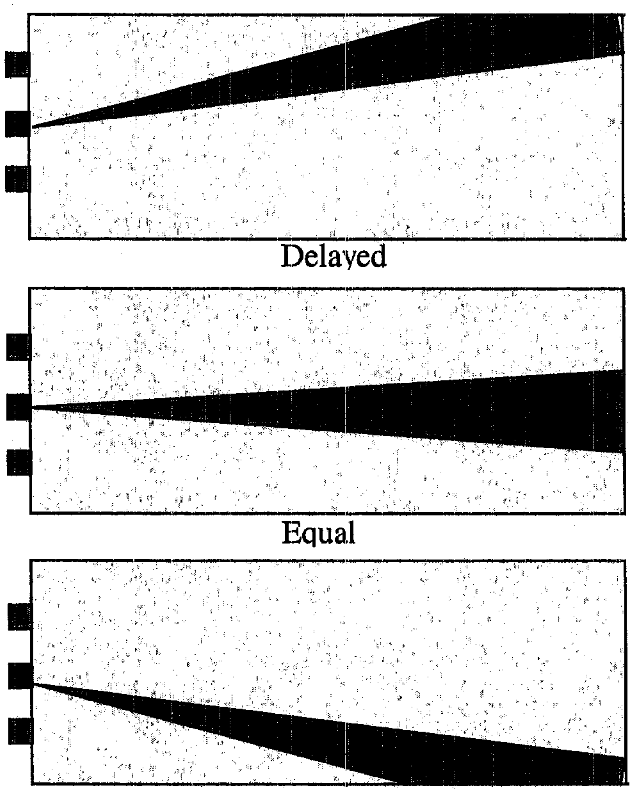

Figure 5. Advancing or delaying the pump wave relative to the probe can change the interaction region inside the rock. This may be able to be used to map the properties of the rock.

III. REFERENCES

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